the diſtance of the primary planet's ſurface from the ſame: and from hence is deduced the proportion between the power of gravity upon the ſurface of one planet, to the gravity upon the ſurface of another. By the like method of comparing the periodical time of a primary planet about the ſun, with the revolution of a ſatellite about its primary, may be found the proportion of gravity, or of the weight of any body upon the ſurface of the ſun, to the gravity, or to the weight of the ſame body upon the ſurface of the planet, which carries about the ſatellite.

17. BY theſe kinds of computation it is found, that the weight of the ſame body upon the ſurface of the ſun will be about 23 times as great, as here upon the ſurface of the earth; about 10, times as great, as upon the ſurface of Jupiter; and near 19 times as great, as upon the ſurface of Saturn [a].

18. THE quantity of matter, which compoſes each of theſe bodies, is proportional to the power it has upon a body at a given diſtance. By this means it is found, that the ſun contains 1067 times as much matter as Jupiter; Jupiter $158\frac{2}{3}$ times as much as the earth, and $2\frac{5}{6}$ times as much as Saturn [b]. The diameter of the ſun is about 92 times, that of Jupiter about 9 times, and that of Saturn about 7 times the diameter of the earth.

[a] Newt. Princ. Lib. III. prop. 8. coroll. 1.

[b] Ibid. coroll. 2.

19. BY making a compariſon between the quantity of matter in theſe bodies and their magnitudes, to be found from their diameters, their reſpective denſities are readily deduced; the denſity of every body being meaſured by the quantity of matter contained under the ſame bulk, as has been above remarked [a]. Thus the earth is found $4\frac{1}{4}$ times more denſe than Jupiter; Saturn has between $\frac{2}{3}$ and $\frac{3}{4}$ of the denſity of Jupiter; but the ſun has one fourth part only of the denſity of the earth [b]. From which this obſervation is drawn by our author; that the ſun is rarified by its great heat, and that of the three planets named, the more denſe is nearer the ſun than the more rare; as was highly reaſonable to expect, the denſeſt bodies requiring the greateſt heat to agitate and put their parts in motion; as on the contrary, the planets which are more rare, would be rendered unfit for their office, by the intenſe heat to which the denſer are expoſed. Thus the waters of our ſeas, if removed to the diſtance of Saturn from the ſun, would remain perpetually frozen; and if as near the ſun as Mercury, would conſtantly boil [c].

20. THE denſities of the three planets Mercury, Venus, and Mars, which have no ſatellites, cannot be expreſly aſſigned; but from what is found in the others, it is very probable, that they alſo are of ſuch different degrees of denſity, that univerſally the planet which is neareſt to the ſun, is formed of the moſt compact ſubſtance.

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[a] Book I. Ch. 4. § 2. [b] Newt. Princ. Lib. III. prop. 8. coroll. 3. [c] Ibid. coroll. 4.

CHAP. VI.

Of the FLUID PARTS of the PLANETS.

THIS globe, that we inhabit, is compoſed of two parts; the ſolid earth, which affords us a foundation to dwell upon; and the ſeas and other waters, that furniſh rains and vapours neceſſary to render the earth fruitful, and productive of what is requiſite for the ſupport of life. And that the moon, though but a ſecondary planet, is compoſed in like manner, is generally thought, from the different degrees of light which appear on its ſurface; the parts of that planet, which reflect a dim light, being ſuppoſed to be fluid, and to imbibe the ſun's rays, while the ſolid parts reflect them more copiouſly. Some indeed do not allow this to be a concluſive argument: but whether we can diſtinguiſh the fluid part of the moon's ſurface from the reſt or not; yet it is moſt probable that there are two ſuch different parts, and with ſtill greater reaſon we may aſcribe the like to the other primary planets, which yet more nearly reſemble our earth. The earth is alſo encompaſſed by another fluid the air, and we have before remarked, that probably the reſt of the planets are ſurrounded by the like. Theſe fluid parts in particular engage our author's attention, both by reaſon of ſome remarkable appearances peculiar to them, and likewiſe of ſome effects they have upon the whole bodies to which they belong.

2. Fluids have been already treated of in general, with reſpect to the effect they have upon ſolid bodies moving in them [a]; now we muſt conſider them in reference to the operation of the power of gravity upon them. By this power they are rendered weighty, like all other bodies, in proportion to the quantity of matter, which is contained in them. And in any quantity of a fluid the upper parts preſs upon the lower as much, as any ſolid body would preſs on another, whereon it ſhould lie. But there is an effect of the preſſure of fluids on the bottom of the veſſel, wherein they are contained, which I ſhall particularly explain. The force ſupported by the bottom of ſuch a veſſel is not ſimply the weight of the quantity of the fluid in the veſſel, but is equal to the weight of that quantity of the fluid, which would be contained in a veſſel of the ſame bottom and of equal width throughout, when this veſſel is filled up to the ſame height, as that to which the veſſel propoſed is filled. Suppoſe water were contained in the veſſel ABCD (in fig. 109.) filled up to EF. Here it is evident, that if a part of the bottom, as GH, which is directly under any part of the ſpace EF, be conſidered ſeparately; it will appear at once, that this part ſuſtains the weight of as much of the fluid, as ſtands perpendicularly over it up to the height of EF; that is, the two perpendiculars GI and HK being drawn, the part GH of the bottom will ſuſtain the whole weight of the fluid included between theſe two perpendiculars. Again, I ſay, every other part of the bottom equally broad with this, will ſuſtain as great a preſſure. Let the part LM be of the

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[a] Book I. Ch. 4.

ſame breadth with GH. Here the perpendiculars LO and MN being drawn, the quantity of water contained between theſe perpendiculars is not ſo great, as that contained between the perpendiculars GI and HK; yet, I ſay, the preſſure on LM will be equal to that on GH. This will appear by the following conſiderations. It is evident, that if the part of the veſſel between O and N were removed, the water would immediately flow out, and the ſurface EF would ſubſide; for all parts of the water being equally heavy, it muſt ſoon form itſelf to a level ſurface, if the form of the veſſel, which contains it, does not prevent. Therefore ſince the water is prevented from riſing by the ſide NO of the veſſel, it is manifeſt, that it muſt preſs againſt NO with ſome degree of force. In other words, the water between the perpendiculars LO and MN endeavours to extend itſelf with a certain degree of force; or more correctly, the ambient water preſſes upon this, and endeavours to force this pillar or column of water into a greater length. But ſince this column of water is ſuſtained between NO and LM, each of theſe parts of the veſſel will be equally preſſed againſt by the power, wherewith this column endeavours to extend. Conſequently LM bears this force over and above the weight of the column of water between LO and MN. To know what this expanſive force is, let the part ON of the veſſel be removed, and the perpendiculars LO and MN be prolonged; then by means of ſome pipe fixed over NO let water be filled between theſe perpendiculars up to PQ an equal height with EF. Here the water between the perpendiculars LP and MQ is of an equal height with the higheſt part of the water in the veſſel; therefore the water in the veſſel cannot by its preſſure force it up higher, nor can the water in this column ſubſide; becauſe, if it ſhould, it would raiſe the water in the veſſel to a greater height than itſelf. But it follows from hence, that the weight of water contained between PO and QN is a juſt balance to the force, wherewith the column between LO and MN endeavours to extend. So the part LM of the bottom, which ſuſtains both this force and the weight of the water between LO and MN, is preſſed upon by a force equal to the united weight of the water between LO and MN, and the weight of the water between PO and QN; that is, it is preſſed on by a force equal to the weight of all the water contained between LP and MQ. And this weight is equal to that of the water contained between GI and HK, which is the weight ſuſtained by the part GH of the bottom. Now this being true of every part of the bottom BC, it is evident, that if another veſſel RSTV be formed with a bottom RV equal to the bottom BC, and be throughout its whole height of one and the ſame breadth; when this veſſel is filled with water to the ſame height, as the veſſel ABCD is filled, the bottoms of theſe two veſſels ſhall be preſſed upon with equal force. If the veſſel be broader at the top than at the bottom, it is evident, that the bottom will bear the preſſure of ſo much of the fluid, as is perpendicularly over it, and the ſides of the veſſel will ſupport the reſt. This property of fluids is a corollary from a propoſition of our author[a]; from whence alſo he deduces the effects of the preſſure of fluids on bodies reſting in them.

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[a] Lib. II. prop. 20. cor. 2.

Theſe are, that any body heavier than a fluid will ſink to the bottom of the veſſel, wherein the fluid is contained, and in the fluid will weigh as much as its own weight exceeds the weight of an equal quantity of the fluid; any body uncompreſſible of the ſame denſity with the fluid, will reſt any where in the fluid without ſuffering the leaſt change either in its place or figure from the preſſure of ſuch a fluid, but will remain as undiſturbed as the parts of the fluid themſelves; but every body of leſs denſity than the fluid will ſwim on its ſurface, a part only being received within the fluid. Which part will be equal in bulk to a quantity of the fluid, whoſe weight is equal to the weight of the whole body; for by this means the parts of the fluid under the body will ſuffer as great a preſſure as any other parts of the fluid as much below the ſurface as theſe.

3. IN the next place, in relation to the air, we have above made mention, that the air ſurrounding the earth being an elaſtic fluid, the power of gravity will have this effect on it, to make the lower parts near the ſurface of the earth more compact and compreſſed together by the weight of the air incumbent, than the higher parts, which are preſſed upon by a leſs quantity of the air, and therefore ſuſtain a leſs weight [a]. It has been alſo obſerved, that our author has laid down a rule for computing the exact degree of denſity in the air at all heights from the earth [b]. But there is a farther effect from the air's being compreſſed by

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[a] Chap. 4. § 17.

[b] Ibid.

the power of gravity, which he has diſtinctly conſidered. The air being elaſtic and in a ſtate of compreſſion, any tremulous body will propagate its motion to the air, and excite therein vibrations, which will ſpread from the body that occaſions them to a great diſtance. This is the efficient cauſe of ſound: for that ſenſation is produced by the air, which, as it vibrates, ſtrikes againſt the organ of hearing. As this ſubject was extremely difficult, ſo our great author's ſucceſs is ſurprizing.

4. OUR author's doctrine upon this head I ſhall endeavour to explain ſomewhat at large. But preliminary thereto muſt be ſhewn, what he has delivered in general of preſſure propagated through fluids; and alſo what he has ſet down relating to that wave-like motion, which appears upon the ſurface of water, when agitated by throwing any thing into it, or by the reciprocal motion of the finger, &c.

5. CONCERNING the firſt, it is proved, that preſſure is ſpread through fluids, not only right forward in a ſtreight line, but alſo laterally, with almoſt the ſame eaſe and force. Of which a very obvious exemplification by experiment is propoſed: that is, to agitate the ſurface of water by the reciprocal motion of the finger forwards and backwards only; for though the finger have no circular motion given it, yet the waves excited in the water will diffuſe themſelves on each hand of the direction of the motion, and ſoon ſurround the finger. Nor is what we obſerve in ſounds unlike to this, which do not proceed in ſtraight lines only, but are heard though a

mountain intervene, and when they enter a room in any part of it, they ſpread themſelves into every corner; not by reflection from the walls, as ſome have imagined, but as far as the ſenſe can judge, directly from the place where they enter.

6. How the waves are excited in the ſurface of ſtagnant water, may be thus conceived. Suppoſe in any place, the water raiſed above the reſt in form of a ſmall hillock; that water will immediately ſubſide, and raiſe the circumambient water above the level of the parts more remote, to which the motion cannot be communicated under longer time. And again, the water in ſubſiding will acquire, like all falling bodies, a force, which will carry it below the level ſurface, till at length the preſſure of the ambient water prevailing, it will riſe again, and even with a force like to that wherewith it deſcended, which will carry it again above the level. But in the mean time the ambient water before raiſed will ſubſide, as this did, ſinking below the level; and in ſo doing, will not only raiſe the water, which firſt ſubſided, but alſo the water next without itſelf. So that now beſide the firſt hillock, we ſhall have a ring inveſting it, at ſome diſtance raiſed above the plain ſurface likewiſe; and between them the water will be ſunk below the reſt of the ſurface. After this, the firſt hillock, and the new made annular riſing, will deſcend; raiſing the water between them, which was before depreſſed, and likewiſe the adjacent part of the ſurface without. Thus will theſe annular waves be ſucceſſively ſpread more and more. For, as the hillock ſubſiding produces one ring, and that ring ſub-

ſiding raiſes again the hillock, and a ſecond ring; ſo the hillock and ſecond ring ſubſiding together raiſe the firſt ring, and a third; then this firſt and third ring ſubſiding together raiſe the firſt hillock, the ſecond ring, and a fourth; and ſo on continually, till the motion by degrees ceaſes. Now it is demonſtrated, that theſe rings aſcend and deſcend in the manner of a pendulum; deſcending with a motion continually accelerated, till they become even with the plain ſurface of the fluid, which is half the ſpace they deſcend; and then being retarded again by the ſame degrees as thoſe, whereby they were accelerated, till they are depreſſed below the plain ſurface, as much as they were before raiſed above it: and that this augmentation and diminution of their velocity proceeds by the ſame degrees, as that of a pendulum vibrating in a cycloid, and whoſe length ſhould be a fourth part of the diſtance between any two adjacent waves: and farther, that a new ring is produced every time a pendulum, whoſe length is four times the former, that is, equal to the interval between the ſummits of two waves, makes one oſcillation or ſwing [a].

7. THIS now opens the way for underſtanding the motion conſequent upon the tremors of the air, excited by the vibrations of ſonorous bodies: which we muſt conceive to be performed in the following manner.

8 LET A, B, C, D, E, F, G, H (in fig. 110.) repreſent a ſeries of the particles of the air, at equal diſtances from each other. IKL a muſical chord, which I ſhall uſe for the tre-

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[a] Vid. Newt. Princ. Lib. II. prop. 46.

mulous and ſonorous body, to make the conception as ſimple as may be. Suppoſe this chord ſtretched upon the points I and L, and forcibly drawn into the ſituation IKL, ſo that it become contiguous to the particle A in its middle point K: and let the chord from this ſituation begin to recoil, preſſing againſt the particle A, which will thereby be put into motion towards B: but the particles A, B, C being equidiſtant, the elaſtic power, by which B avoids A, is equal to, and balanced by the power, by which it avoids C; therefore the elaſtic force, by which B is repelled from A, will not put B into any degree of motion, till A is by the motion of the chord brought nearer to B, than B is to C: but as ſoon as that is done, the particle B will be moved towards C; and being made to approach C, will in the next place move that; which will upon that advance, put D likewiſe into motion, and ſo on: therefore the particle A being moved by the chord, the following particles of the air B, C, D, &c. will ſucceſſively be moved. Farther, if the point K of the chord moves forward with an accelerated velocity, ſo that the particle A ſhall move againſt B with an advancing pace, and gain ground of it, approaching nearer and nearer continually; A by approaching will preſs more upon B, and give it a greater velocity likewiſe, by reaſon that as the diſtance between the particles diminiſhes, the elaſtic power, by which they fly each other, increaſes. Hence the particle B, as well as A, will have its motion gradually accelerated, and by that means will more and more approach to C. And from the ſame cauſe C will more and more approach D; and ſo of the reſt. Suppoſe now, ſince the agitation of theſe particles has been ſhewn to be ſucceſſive, and to follow one another, that E be the remoteſt particle moved, while the chord is moving from its curve ſituation IKL into that of a ſtreight line, as I*k*L; and F the firſt which remains unaffected, though juſt upon the point of being put into motion. Then ſhall the particles A, B, C, D, E, F, G, when the point K is moved into *k*, have acquired the rangement repreſented by the adjacent points *a*, *b*, *c*, *d*, *e*, *f*, *g*: in which *a* is nearer to *b* than *b* to *c*, and *b* nearer to *c* than *c* to *d*, and *c* nearer to *d* than *d* to *e*, and *d* nearer to *e* than *e* to *f*, and laſtly *e* nearer to *f* than *f* to *g*.

9. BUT now the chord having recovered its rectilinear ſituation I*k*L, the following motion will be changed, for the point K, which before advanced with a motion more and more accelerated, though by the force it has acquired it will go on to move the ſame way as before, till it has advanced near as far forwards, as it was at firſt drawn backwards; yet the motion of it will henceforth be gradually leſſened. The effect of which upon the particles *a*, *b*, *c*, *d*, *e*, *f*, *g* will be, that by the time the chord has made its utmoſt advance, and is upon the return, theſe particles will be put into a contrary rangement; ſo that *f* ſhall be nearer to *g*, than *e* to *f*, and *e* nearer to *f* than *d* to *e*; and the like of the reſt, till you come to the firſt particles *a*, *b*, whoſe diſtance will then be nearly or quite what it was at firſt. All which will appear as follows. The preſent diſtance between *a* and *b* is ſuch, that the elaſtic power, by which *a* repels *b*, is ſtrong enough to maintain that diſtance, though *a* advance with the velocity, with which the ſtring reſumes its rectilinear figure; and the

motion of the particle *a* being afterwards ſlower, the preſent elaſticity between *a* and *b* will be more than ſufficient to preſerve the diſtance between them. Therefore while it accelerates *b* it will retard *a*. The diſtance *bc* will ſtill diminiſh, till *b* come about as near to *c*, as it is from *a* at preſent; for after the diſtances *ab* and *bc* are become equal, the particle *b* will continue its velocity ſuperior to that of *c* by its own power of inactivity, till ſuch time as the increaſe of elaſticity between *b* and *c* more than ſhall be between *a* and *b* ſhall ſuppreſs its motion: for as the power of inactivity in *b* made a greater elaſticity neceſſary on the ſide of *a* than on the ſide of *c* to puſh *b* forward, ſo what motion *b* has acquired it will retain by the ſame power of inactivity, till it be ſuppreſſed by a greater elaſticity on the ſide of *c*, than on the ſide of *a*. But as ſoon as *b* begins to ſlacken its pace the diſtance of *b* from *c* will widen as the diſtance *ab* has already done. Now as *a* acts on *b*, ſo will *b* on *c*, *c* on *d*, &c. ſo that the diſtances between all the particles *a*, *b*, *c*, *d*, *e*, *f*, *g* will be ſucceſſively contracted into the diſtance of *a* from *b*, and then dilated again. Now becauſe the time, in which the chord deſcribes this preſent half of its vibration, is about equal to that it took up in deſcribing the former; the particles *a*, *b* will be as long in dilating their diſtance, as before in contracting it, and will return nearly to their original diſtance. And farther, the particles *b*, *c*, which did not begin to approach ſo ſoon as *a*, *b*, are now about as much longer, before they begin to recede; and likewiſe the particles *c*, *d*, which began to approach after *b*, *c*, begin to ſeparate later. Whence it appears that the particles, whoſe diſtance began to be leſſened, when the preceding one be equal to its original diſtance; the whole chain α, β, γ, δ, ε, ζ, η, having an undulating motion forward, which is ſtopt gradually by the exceſs of the expanſive power of the preceding parts above that of the hinder. Thus are theſe parts ſucceſſively ſtopt, as before they were moved; ſo that when the chord has regained its rectilinear ſituation, the expanſion of the parts of the air will have advanced ſo far, that the interval between ζ η, which at preſent is moſt contracted, will then be reſtored to its natural ſize: the diſtances between η and θ, θ and λ, λ and μ, μ and ν, ν and ξ, being ſucceſſively contracted into the preſent diſtance of ζ from η, and again enlarged; ſo that the ſame effect ſhall be produced upon the parts beyond ζ η, by the enlargement of the diſtance between thoſe two particles, as was occaſioned upon the particles α, β, γ, δ, ε, ζ, η, θ, λ, μ, ν, ξ, by the enlargement of the diſtance α β to its natural extent. And therefore the motion in the air will be extended half as much farther as at preſent, and the diſtance between ν and ξ contracted into that, which is at preſent between ζ and η, all the particles of the air in motion taking the rangement expreſſed in figure 111. by the points α, β, γ, δ, ε, ζ, η, θ, λ, μ, ν, ξ, π, ρ, σ, τ, φ; wherein the particles from α to ξ have their diſtances from each other gradually diminiſhed, the diſtances between the particles ν, ξ being contracted the moſt from the natural diſtance between thoſe particles, and the diſtance between α, β as much augmented, and the diſtance between the middle particles ζ, η becoming equal to the natural. The particles π, ρ, σ, τ, φ, which follow ξ, have their diſtances gradually greater and greater, the particles ν, ξ, π, ρ, σ, τ, φ being ranged like the particles a, b, c, d, e, f, g, or like the particles ζ, η, θ, λ, μ, ν, ξ in the former figure. Here it will be underſtood, by what has been before explained, that the particles ζ, η being at their natural diſtance from each other, the particle ζ is at reſt, the particles ε, δ, γ, β, α between them and the ſtring being in motion backward, and the reſt of the particles η, θ, λ, μ, ν, ξ, π, ρ, σ, τ in motion forward: each of the particles between η and ξ moving faſter than that, which immediately follows it; but of the particles from ξ to φ, on the contrary, thoſe behind moving on faſter than thoſe, which precede.

11. BUT now the ſtring having recovered its rectilinear figure, though it ſhall go on recoiling, till it return near to its firſt ſituation IKL, yet there will be a change in its motion; ſo that whereas it returned from the ſituation IκL with an accelerated motion, its motion ſhall from hence be retarded again by the ſame degrees, as accelerated before. The effect of which change upon the particles of the air will be this. As by the accelerated motion of the chord α contiguous to it moved faſter than β, ſo as to make the interval $\alpha\beta$ greater than the interval $\beta\gamma$, and from thence β was made likewiſe to move faſter than γ, and the diſtance between β and γ rendered greater than the diſtance between γ and δ, and ſo of the reſt; now the motion of α being diminiſhed, β ſhall overtake it, and the diſtance between α and β be reduced into that, which is at preſent between β and γ, the interval between β and γ being inlarged into the pre-

ſent diſtance between α and β; but when the interval $\beta\,\gamma$ is increaſed to that, which is at preſent between α and β, the diſtance between γ and δ ſhall be enlarged to the preſent diſtance between γ and β, and the diſtance between δ and ϵ inlarged into the preſent diſtance between γ and δ; and the ſame of the reſt. But the chord more and more ſlackening its pace, the diſtance between α and β ſhall be more and more diminiſhed; and in conſequence of that the diſtance between β and γ ſhall be again contracted, firſt into its preſent dimenſion, and afterwards into a narrower ſpace; while the interval $\gamma\,\delta$ ſhall dilate into that at preſent between α and β, and as ſoon as it is ſo much enlarged, it ſhall contract again. Thus by the reciprocal expanſion and contraction of the air between α and ζ, by that time the chord is got into the ſituation I K L, the interval $\zeta\,\eta$ ſhall be expanded into the preſent diſtance between α and β; and by that time likewiſe the preſent diſtance of α from β will be contracted into their natural interval: for this diſtance will be about the ſame time in contracting it ſelf, as has been taken up in its dilatation; ſeeing the ſtring will be as long in returning from its rectilinear figure, as it has been in recovering it from its ſituation I κ L. This is the change which will be made in the particles between α and ζ. As for thoſe between ζ and ξ, becauſe each preceding particle advances faſter than that, which immediately follows it, their diſtances will ſucceſſively be dilated into that, which is at preſent between ζ and η. And as ſoon as any two particles are arrived at their natural diſtance, the hindermoſt of them ſhall be ſtopt, and immediately after return, the diſtances between the returning particles being greater than the natural. And this dilatation of theſe diſtances ſhall extend ſo far, by that time the chord is returned into its firſt ſituation IKL, that the particles $\nu\xi$ ſhall be removed to their natural diſtance. But the dilatation of $\nu\xi$ ſhall contract the interval $\tau\varphi$ into that at preſent between ν and ξ, and the contraction of the diſtance between thoſe two particles τ and φ will agitate a part of the air beyond; ſo that when the chord is returned into the ſituation IKL, having made an intire vibration, the moved particles of the air will take the rangement expreſſed by the points, $l, m, n, o, p, q, r, s, t, u, w, x, y, z$, 1, 2, 3, 4, 5, 6, 7, 8: in which lm, are at the natural diſtance of the particles, the diſtance mn greater than lm, and no greater than mn, and ſo on, till you come to qr, the wideſt of all: and then the diſtances gradually diminiſh not only to the natural diſtance, as wx, but till they are contracted as much as $\xi\pi$ was before; which falls out in the points 2, 3, from whence the diſtances augment again, till you come to the part of the air untouched.

12. THIS is the motion, into which the air is put, while the chord makes one vibration, and the whole length of air thus agitated in the time of one vibration of the chord our author calls the length of one pulſe. When the chord goes on to make another vibration, it will not only continue to agitate the air at preſent in motion, but ſpread the pulſation of the air as much farther, and by the ſame degrees, as before. For when the chord returns into its rectilinear ſituation IkL, lm ſhall be brought into its moſt contracted

ſtate, *qr* now in the ſtate of greateſt dilatation ſhall be reduced to its natural diſtance, the points *w*, *x* now at their natural diſtance ſhall be at their greateſt diſtance, the points 2, 3 now moſt contracted enlarged to their natural diſtance, and the points 7, 8 reduced to their moſt contracted ſtate: and the contraction of them will carry the agitation of the air as far beyond them, as that motion was carried from the chord, when it firſt moved out of the ſituation I K L into its rectilinear figure. When the chord is got into the ſituation I *x* L, *lm* ſhall recover its natural dimenſions, *qr* be reduced to its ſtate of greateſt contraction, *w x* brought to its natural dimenſion, the diſtance 2 3 enlarged to the utmoſt, and the points 7, 8 ſhall have recovered their natural diſtance; and by thus recovering themſelves they ſhall agitate the air to as great a length beyond them, as it was moved beyond the chord, when it firſt came into the ſituation I *x* L. When the chord is returned back again into its rectilinear ſituation, *lm* ſhall be in its utmoſt dilatation, *qr* reſtored again to its natural diſtance, *w x* reduced into its ſtate of greateſt contraction, 2 3 ſhall recover its natural dimenſion, and 7 8 be in its ſtate of greateſt dilatation. By which means the air ſhall be moved as far beyond the points 7, 8, as it was moved beyond the chord, when it before made its return back to its rectilinear ſituation; for the particles 7, 8 have been changed from their ſtate of reſt and their natural diſtance into a ſtate of contraction, and then have proceeded to the recovery of their natural diſtance, and after that to a dilatation of it, in the ſame manner as the particles contiguous to the chord were agitated before. In the laſt place, when the chord is returned into the ſituation IKL, the particles of air from l to λ ſhall acquire their preſent rangement, and the motion of the air be extended as much farther. And the like will happen after every compleat vibration of the ſtring.

13. Concerning this motion of ſound, our author ſhews how to compute the velocity thereof, or in what time it will reach to any propoſed diſtance from the ſonorous body. For this he requires to know the height of air, having the ſame denſity with the parts here at the ſurface of the earth, which we breath, that would be equivalent in weight to the whole incumbent atmoſphere. This is to be found by the barometer, or common weatherglaſs. In that inſtrument quickſilver is included in a hollow glaſs cane firmly cloſed at the top. The bottom is open, but immerged into quickſilver contained in a veſſel open to the air. Care is taken when the lower end of the cane is immerged, that the whole cane be full of quickſilver, and that no air inſinuate itſelf. When the inſtrument is thus fixed, the quickſilver in the cane being higher than that in the veſſel, if the top of the cane were open, the fluid would ſoon ſink out of the glaſs cane, till it came to a level with that in the veſſel. But the top of the cane being cloſed up, ſo that the air, which has free liberty to preſs on the quickſilver in the veſſel, cannot bear at all on that, which is within the cane, the quickſilver in the cane will be ſuſpended to ſuch a height, as to balance the preſſure of the air on the quickſilver in the veſſel. Here it is evident, that the

weight of the quickſilver in the glaſs cane is equivalent to the preſſure of ſo much of the air, as is perpendicularly over the hollow of the cane; for if the cane be opened that the air may enter, there will be no farther uſe of the quickſilver to ſuſtain the preſſure of the air without; for the quickſilver in the cane, as has already been obſerved, will then ſubſide to a level with that without. Hence therefore if the proportion between the denſity of quickſilver and of the air we breath be known, we may know what height of ſuch air would form a column equal in weight to the column of quickſilver within the glaſs cane. When the quickſilver is ſuſtained in the barometer at the height of 30 inches, the height of ſuch a column of air will be about 29725 feet; for in this caſe the air has about $\frac{1}{870}$ of the denſity of water, and the denſity of quickſilver exceeds that of water about $13\frac{2}{3}$ times, ſo that the denſity of quickſilver exceeds that of the air about 11890 times; and ſo many times 30 inches make 29725 feet. Now Sir Isaac Newton determines, that while a pendulum of the length of this column ſhould make one vibration or ſwing, the ſpace, which any ſound will have moved, ſhall bear to this length the ſame proportion, as the circumference of a circle bears to the diameter thereof; that is, about the proportion of 355 to 113[a]. Only our author here conſiders ſingly the gradual progreſs of ſound in the air from particle to particle in the manner we have explained, without taking into conſideration the magnitude of thoſe particles. And though there requires time for the motion to be propagated from one par-

[a] Princ. philoſ. Lib. II. prop. 49.

ticle to another, yet it is communicated to the whole of the ſame particle in an inſtant: therefore whatever proportion the thickneſs of theſe particles bears to their diſtance from each other, in the ſame proportion will the motion of ſound be ſwifter. Again the air we breath is not ſimply compoſed of the elaſtic part, by which ſound is conveyed, but partly of vapours, which are of a different nature; and in the computation of the motion of ſound we ought to find the height of a column of this pure air only, whoſe weight ſhould be equal to the weight of the quickſilver in the cane of the barometer, and this pure air being a part only of that we breath, the column of this pure air will be higher than 29725 feet. On both theſe accounts the motion of ſound is found to be about 1142 feet in one ſecond of time, or near 13 miles in a minute, whereas by the computation propoſed above, it ſhould move but 979 feet in one ſecond.

14. We may obſerve here, that from theſe demonſtrations of our author it follows, that all ſounds whether acute or grave move equally ſwift, and that ſound is ſwifteſt, when the quickſilver ſtands higheſt in the barometer.

15. Thus much of the appearances, which are cauſed in theſe fluids from their gravitation toward the earth. They alſo gravitate toward the moon; for in the laſt chapter it has been proved, that the gravitation between the earth and moon is mutual, and that this gravitation of the whole bodies ariſes from that power acting in all their parts; ſo that

every particle of the moon gravitates toward the earth, and every particle of the earth toward the moon. But this gravitation of theſe fluids toward the moon produces no ſenſible effect, except only in the ſea, where it cauſes the tides.

16. That the tides depend upon the influence of the moon has been the receiv'd opinion of all antiquity; nor is there indeed the leaſt ſhadow of reaſon to ſuppoſe otherwiſe, conſidering how ſteadily they accompany the moon's courſe. Though how the moon cauſed them, and by what principle it was enabled to produce ſo diſtinguiſh'd an appearance, was a ſecret left for this philoſophy to unfold: which teaches, that the moon is not here alone concerned, but that the ſun likewiſe has a conſiderable ſhare in their production; though they have been generally aſcribed to the other luminary, becauſe its effect is greateſt, and by that means the tides more immediately ſuit themſelves to its motion; the ſun diſcovering its influence more by enlarging or reſtraining the moon's power, than by any diſtinct effects. Our author finds the power of the moon to bear to the power of the ſun about the proportion of $4\frac{1}{2}$ to 1. This he deduces from the obſervations made at the mouth of the river Avon, three miles from Briſtol, by Captain Sturmey, and at Plymouth by Mr. Colepresse, of the height to which the water is raiſed in the conjunction and oppoſition of the luminaries, compared with the elevation of it, when the moon is in either quarter; the firſt being cauſed

by the united actions of the ſun and moon, and the other by the difference of them, as ſhall hereafter be ſhewn.

17. THAT the ſun ſhould have a like effect on the ſea, as the moon, is very manifeſt; ſince the ſun likewiſe attracts every ſingle particle, of which this earth is compoſed. And in both luminaries ſince the power of gravity is reciprocally in the duplicate proportion of the diſtance, they will not draw all the parts of the waters in the ſame manner; but muſt act upon the neareſt parts ſtronger, than upon the remoteſt, producing by this inequality an irregular motion. We ſhall now attempt to ſhew how the actions of the ſun and moon on the waters, by being combined together, produce all the appearances obſerved in the tides.

18. TO begin therefore, the reader will remember what has been ſaid above, that if the moon without the ſun would have deſcribed an orbit concentrical to the earth, the action of the ſun would make the orbit oval, and bring the moon nearer to the earth at the new and full, than at the quarters[a]. Now our excellent author obſerves, that if inſtead of one moon, we ſuppoſe a ring of moons, contiguous and occupying the whole orbit of the moon, his demonſtration would ſtill take place, and prove that the parts of this ring in paſſing from the quarter to the conjunction or oppoſition would be accelerated, and be retarded again in paſſing from the conjunction or oppoſition to the next quarter. And as this effect does not de-

[a] Chap. 3. § 18.

pend on the magnitude of the bodies, whereof the ring is compoſed, the ſame would hold, though the magnitude of theſe moons were ſo far to be diminiſhed, and their number increaſed, till they ſhould form a fluid [a]. Now the earth turns round continually upon its own center, cauſing thereby the alternate change of day and night, while by this revolution each part of the earth is ſucceſſively brought toward the ſun, and carried off again in the ſpace of 24 hours. And as the ſea revolves round along with the earth itſelf in this diurnal motion, it will repreſent in ſome ſort ſuch a fluid ring.

19. BUT as the water of the ſea does not move round with ſo much ſwiftneſs, as would carry it about the center of the earth in the circle it now deſcribes, without being ſupported by the body of the earth; it will be neceſſary to conſider the water under three diſtinct caſes. The firſt caſe ſhall ſuppoſe the water to move with the degree of ſwiftneſs, required to carry a body round the center of the earth diſingaged from it in a circle at the diſtance of the earth's ſemidiameter, like another moon. The ſecond caſe is, that the waters make but one turn about the axis of the earth in the ſpace of a month, keeping pace with the moon; ſo that all parts of the water ſhould preſerve continually the ſame ſituation in reſpect of the moon. The third caſe ſhall be the real one of the waters moving with a velocity between theſe two, neither ſo ſwift as the firſt caſe requires, nor ſo ſlow as the ſecond.

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[a] Newt. Princ. philoſ. Lib. I. prop. 66. coroll. 18.

20. In the firſt caſe the waters, like the body which they equalled in velocity, by the action of the moon would be brought nearer the center under and oppoſite to the moon, than in the parts in the middle between theſe eaſtward or weſtward. That ſuch a body would ſo alter its diſtance by the moon's action upon it, is clear from what has been mentioned of the like changes in the moon's motion cauſed by the ſun [a]. And computation ſhews, that the difference between the greateſt and leaſt diſtance of ſuch a body would not be much above 4 $\frac{1}{2}$ feet. But in the ſecond caſe, where all the parts of the water preſerve the ſame ſituation continually in reſpect of the moon, the weight of thoſe parts under and oppoſite to the moon will be diminiſhed by the moon's action, and the parts in the middle between theſe will have their weight increaſed: this being effected juſt in the ſame manner, as the ſun diminiſhes the attraction of the moon towards the earth in the conjunction and oppoſition, but increaſes that attraction in the quarters. For as the firſt of theſe conſequences from the ſun's action on the moon is occaſioned by the moon's being attracted by the ſun in the conjunction more than the earth, and in the oppoſition leſs than it, and therefore in the common motion of the earth and moon, the moon is made to advance toward the ſun in one caſe too faſt, and in the other is left as it were behind; ſo the earth will not have its middle parts drawn towards the moon ſo ſtrongly as the nearer parts, and yet more forcibly than the remoteſt: and therefore ſince the earth and moon move each

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[a] § 8.

month round their common center of gravity [a], while the earth moves round this center, the ſame effect will be produced, on the parts of the water neareſt to that center or to the moon, as the moon feels from the ſun when in conjunction, and the water on the contrary ſide of the earth will be affected by the moon, as the moon is by the ſun, when in oppoſition [b]; that is, in both caſes the weight of the water, or its propenſity towards the center of the earth, will be diminiſhed. The parts in the middle between theſe will have their weight increaſed, by being preſſed towards the center of the earth through the obliquity of the moon's action upon them to its action upon the earth's center, juſt as the ſun increaſes the gravitation of the moon in the quarters from the ſame cauſe [c]. But now it is manifeſt, that where the weight of the ſame quantity of water is leaſt, there it will be accumulated; while the parts, which have the greateſt weight, will ſubſide. Therefore in this caſe there would be no tide or alternate riſing and falling of the water, but the water would form it ſelf into an oblong figure, whoſe axis prolonged would paſs through the moon. By Sir ISAAC NEWTON's computation the exceſs of this axis above the diameters perpendicular to it, that is, the height of the waters under and oppoſite to the moon above their height in the middle between theſe places eaſtward or weſtward cauſed by the moon, is about $8\frac{2}{5}$ feet.

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[a] Ch. 3. § 5.

[b] Ch. 3. § 17.

[c] Ibid.

21. Thus the difference of height in this latter ſuppoſition is little ſhort of twice that difference in the preceding. But the caſe of the ſea is a middle between theſe two: for a body, which ſhould revolve round the center of the earth at the diſtance of a ſemidiameter without preſſing on the earth's ſurface, muſt perform its period in leſs than an hour and half, whereas the earth turns round but once in a day; and in the caſe of the waters keeping pace with the moon it ſhould turn round but once in a month: ſo that the real motion of the water is between the motions required in theſe two caſes. Again, if the waters moved round as ſwiftly as the firſt caſe required, their weight would be wholly taken off by their motion; for this caſe ſuppoſes the body to move ſo, as to be kept revolving in a circle round the earth by the power of gravity without preſſing on the earth at all, ſo that its motion juſt ſupports its weight. But if the power of gravity had been only $\frac{1}{289}$ part of what it is, the body could have moved thus without preſſing on the earth, and have been as long in moving round, as the earth it ſelf is. Conſequently the motion of the earth takes off from the weight of the water in the middle between the poles, where its motion is ſwifteſt, $\frac{1}{289}$ part of its weight and no more. Since therefore in the firſt caſe the weight of the waters muſt be intirely taken off by their motion, and by the real motion of the earth they loſe only $\frac{1}{289}$ part thereof, the motion of the water will ſo little diminiſh their weight, that their figure will much nearer reſemble the caſe of their keeping pace with the moon than the other. Upon the whole, if the waters moved with the

velocity neceſſary to carry a body round the center of the earth at the diſtance of the earth's ſemidiameter without bearing on its ſurface, the water would be loweſt under the moon, and riſe gradually as it moved on with the earth eaſtward, till it came half way toward the place oppoſite to the moon; from thence it would ſubſide again, till it came to the oppoſition, where it would become as low as at firſt; afterwards it would riſe again, till it came half way to the place under the moon; and from hence it would ſubſide, till it came a ſecond time under the moon. But in caſe the water kept pace with the moon, it would be higheſt where in the other caſe it is loweſt, and loweſt where in the other it is higheſt; therefore the diurnal motion of the earth being between the motions of theſe two caſes, it will cauſe the higheſt place of the water to fall between the places of the greateſt height in theſe two caſes. The water as it paſſes from under the moon ſhall for ſome time riſe, but deſcend again before it arrives half way to the oppoſite place, and ſhall come to its leaſt height before it becomes oppoſite to the moon; then it ſhall riſe again, continuing ſo to do till it has paſſed the place oppoſite to the moon, but ſubſide before it comes to the middle between the places oppoſite to and under the moon; and laſtly it ſhall come to its loweſt, before it comes a ſecond time under the moon. If A (in fig. 112, 113, 114.) repreſent the moon, B the center of the earth, the oval CDEF in fig. 112. will repreſent the ſituation of the water in the firſt caſe; but if the water kept pace with the moon, the line CDEF in fig. 113. would repreſent the ſituation of the water; but the line CDEF in fig. 114. will repreſent the ſame in the real motion of the water, as it accompanies the earth in its diurnal rotation: in all theſe figures C and E being the places where the water is loweſt, and D and F the places where it is higheſt. Purſuant to this determination it is found, that on the ſhores, which lie expoſed to the open ſea, the high water uſually falls out about three hours after the moon has paſſed the meridian of each place.

22. Let this ſuffice in general for explaining the manner, in which the moon acts upon the ſeas. It is farther to be noted, that theſe effects are greateſt, when the moon is over the earth's equator[a], that is, when it ſhines perpendicularly upon the parts of the earth in the middle between the poles. For if the moon were placed over either of the poles, it could have no effect upon the water to make it aſcend and deſcend. So that when the moon declines from the equator toward either pole, it's action muſt be ſomething diminiſhed, and that the more, the farther it declines. The tides likewiſe will be greateſt, when the moon is neareſt to the earth, it's action being then the ſtrongeſt.

23. Thus much of the action of the moon. That the ſun ſhould produce the very ſame effects, though in a leſs degree, is too obvious to require a particular explanation: but as was remarked before, this action of the

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[a] See below § 44.

ſun being weaker than that of the moon, will cauſe the tides to follow more nearly the moon's courſe, and principally ſhew it ſelf by heightening or diminiſhing the effects of the other luminary. Which is the occaſion, that the higheſt tides are found about the conjunction and oppoſition of the luminaries, being then produced by their united action, and the weakeſt tides about the quarters of the moon; becauſe the moon in this caſe raiſing the water where the ſun depreſſes it, and depreſſing it where the ſun raiſes it, the ſtronger action of the moon is in part retunded and weakened by that of the ſun. Our author computes that the ſun will add near two feet to the height of the water in the firſt caſe, and in the other take from it as much. However the tides in both comply with the ſame hour of the moon. But at other times, between the conjunction or oppoſition and quarters, the time deviates from that forementioned, towards the hour in which the ſun would make high water, though ſtill it keeps much nearer to the moon's hour than to the ſun's.

24. AGAIN the tides have ſome farther varieties from the ſituation of the places where they happen northward or ſouthward. Let p P (in fig. 115.) repreſent the axis, on which the earth daily revolves, let hp H P repreſent the figure of the water, and let n B N D be a globe inſcribed within this figure. Suppoſe the moon to be advanced from the equator toward the north pole, ſo that h H the axis of the figure of the water $p$AHPE$h$ ſhall decline towards the north pole N; take any place G nearer to

the north pole than to the ſouth, and from the center of the earth C draw CGE; then will GF denote the altitude to which the water is raiſed by the tide, when the moon is above the horizon: in the ſpace of twelve hours, the earth having turned half round its axis, the place G will be removed to *g*; but the axis *h* H will have kept its place preſerving its ſituation in reſpect of the moon, at leaſt will have moved no more than the moon has done in that time, which it is not neceſſary here to take into conſideration. Now in this caſe the height of the water will be equal to *g f*, which is not ſo great as GF. But whereas GF is the altitude at high water, when the moon is above the horizon, *g f* will be the altitude of the ſame, when the moon is under the horizon. The contrary happens toward the ſouth pole, for KL is leſs than *k l*. Hence is proved, that when the moon declines from the equator, in thoſe places, which are on the ſame ſide of the equator as the moon, the tides are greater, when the moon is above the horizon, than when under it; and the contrary happens on the other ſide of the equator.

25. Now from theſe principles may be explained all the known appearances in the tides; only by the aſſiſtance of this additional remark, that the fluctuating motion, which the water has in flowing and ebbing, is of a durable nature, and would continue for ſome time, though the action of the luminaries ſhould ceaſe; for this prevents the difference between the tide when the moon is above

the horizon, and the tide when the moon is below it from being ſo great, as the rule laid down requires. This likewiſe makes the greateſt tides not exactly upon the new and full moon, but to be a tide or two after; as at Briſtol and Plymouth they are found the third after.

• 26. THIS doctrine farther ſhews us, why not only the ſpring tides fall out about the new and full moon, and the neap tides about the quarters; but likewiſe how it comes to paſs, that the greateſt ſpring tides happen about the equinoxes; becauſe the luminaries are then one of them over the equator, and the other not far from it. It appears too, why the neap tides, which accompany theſe, are the leaſt of all; for the ſun ſtill continuing over the equator continues to have the greateſt power of leſſening the moon's action, and the moon in the quarters being far removed toward one of the poles, has its power thereby weakned.

27. MOREOVER the action of the moon being ſtronger, when near the earth, than when more remote; if the moon, when new ſuppoſe, be at its neareſt diſtance from the earth, it ſhall when at the full be fartheſt off; whence it is, that two of the very largeſt ſpring tides do never immediately ſucceed each other.

28. BECAUSE the ſun in its paſſage from the winter ſolſtice to the ſummer recedes from the earth, and paſſing from the ſummer ſolſtice to the winter approaches it, and is therefore nearer the earth before the vernal equinox than

after, but nearer after the autumnal equinox than before; the greateſt tides oftner precede the vernal equinox than follow it, and in the autumnal equinox on the contrary they oftner follow it than come before it.

29. The altitude, to which the water is raiſed in the open ocean, correſponds very well to the forementioned calculations; for as it was ſhewn, that the water in ſpring tides ſhould riſe to the height of 10 or 11 feet, and the neap tides to 6 or 7; accordingly in the Pacific, Atlantic and Ethiopic oceans in the parts without the tropics, the water is obſerved to riſe about 6, 9, 12 or 15 feet. In the Pacific ocean this elevation is ſaid to be greater than in the other, as it ought to be by reaſon of the wide extent of that ſea. For the ſame reaſon in the Ethiopic ocean between the tropics the aſcent of the water is leſs than without, by reaſon of the narrowneſs of the ſea between the coaſts of Africa and the ſouthern parts of America. And iſlands in ſuch narrow ſeas, if far from ſhore, have leſs tides than the coaſts. But now in thoſe ports where the water flows in with great violence upon fords and ſhoals, the force it acquires by that means will carry it to a much greater height, ſo as to make it aſcend and deſcend to 30, 40 or even 50 feet and more; inſtances of which we have at Plymouth, and in the Severn near Chepſtow; at St. Michael's and Auranches in Normandy; at Cambay and Pegu in the Eaſt Indies.

30. Again the tides take a conſiderable time in paſſing through long ſtraits, and ſhallow places. Thus the tide,

which is made on the weſt coaſt of Ireland and on the coaſt of Spain at the third hour after the moon's coming to the meridian, in the ports eaſtward toward the Britiſh channel falls out later, and as the flood paſſes up that channel ſtill later and later, ſo that the tide takes up full twelve hours in coming up to London bridge.

31. IN the laſt place tides may come to the ſame port from different ſeas, and as they may interfere with each other, they will produce particular effects. Suppoſe the tide from one ſea come to a port at the third hour after the moon's paſſing the meridian of the place, but from another ſea to take up ſix hours more in its paſſage. Here one tide will make high water, when by the other it ſhould be loweſt; ſo that when the moon is over the equator, and the two tides are equal, there will be no riſing and falling of the water at all; for as much as the water is carried off by one tide, it will be ſupplied by the other. But when the moon declines from the equator, the ſame way as the port is ſituated, we have ſhewn that of the two tides of the ocean, which are made each day, that tide, which is made when the moon is above the horizon, is greater than the other. Therefore in this caſe, as four tides come to this port each day the two greateſt will come on the third, and on the ninth hour after the moon's paſſing the meridian, and the two leaſt at the fifteenth and at the twenty firſt hour. Thus from the third to the ninth hour more water will be in this port by the two greateſt tides than from the ninth to the fifteenth, or from the twenty firſt to the

following third hour, where the water is brought by one great and one ſmall tide; but yet there will be more water brought by theſe tides, than what will be found between the two leaſt tides, that is, between the fifteenth and twenty firſt hour. Therefore in the middle between the third and ninth hour, or about the moon's ſetting, the water will be at its greateſt height; in the middle between the ninth and fifteenth, as alſo between the twenty firſt and following third hour it will have its mean height; and be loweſt in the middle between the fifteenth and twenty firſt hour, that is, at the moon's riſing. Thus here the water will have but one flood and one ebb each day. When the moon is on the other ſide of the equator, the flood will be turned into ebb, and the ebb into flood; the high water falling out at the riſing of the moon, and the low water at the ſetting. Now this is the caſe of the port of Batſham in the kingdom of Tunquin in the Eaſt Indies; to which port there are two inlets, one between the continent and the iſlands which are called the Manillas, and the other between the continent and Borneo.

32. The next thing to be conſidered is the effect, which theſe fluids of the planets have upon the ſolid part of the bodies to which they belong. And in the firſt place I ſhall ſhew, that it was neceſſary upon account of theſe fluid parts to form the bodies of the planets into a figure ſomething different from that of a perfect globe. Becauſe the diurnal rotation, which our earth performs about its axis, and the like motion we ſee in ſome of the other planets,

(which is an ample conviction that they all do the like) will diminiſh the force, with which bodies are attracted upon all the parts of their ſurfaces, except at the very poles, upon which they turn. Thus a ſtone or other weighty ſubſtance 'reſting upon the ſurface of the earth, by the force which it receives from the motion communicated to it by the earth, if its weight prevented not, would continue that motion in a ſtraight line from the point where it received it, and according to the direction, in which it was given, that is, in a line which touches the ſurface at that point; inſomuch that it would move off from the earth in the ſame manner, as a weight faſten'd to a ſtring and whirled about endeavours continually to recede from the center of motion, and would forthwith remove it ſelf to a greater diſtance from it, if looſed from the ſtring which retains it. And farther, as the centrifugal force, with which ſuch a weight preſſes from the center of its motion, is greater, by how much greater the velocity is, with which it moves; ſo ſuch a body, as I have been ſuppoſing to lie on the earth, would recede from it with the greater force, the greater the velocity is, with which the part of the earth's ſurface it reſts upon is moved, that is, the farther diſtant it is from the poles. But now the power of gravity is great enough to prevent bodies in any part of the earth from being carried off from it by this means; however it is plain that bodies having an effort contrary to that of gravity, though much weaker than it, their weight, that is, the degree of force, with which they are preſſed to the earth, will be diminiſhed thereby, and be the more diminiſhed, the greater this contrary effort is; or in other words, the ſame body will weigh heavier at either of the poles, than upon any other part of the earth; and if any body be removed from the pole towards the equator, it will loſe ~~of its weight~~ more and more, and be lighteſt of all at the equator, that is, in the middle between the poles.

33. THIS now is eaſily applied to the waters of the ſeas, and ſhews that the water under the poles will preſs more forcibly to the earth, than at or near the equator: and conſequently that which preſſes leaſt, muſt give place, till by aſcending it makes room for receiving a greater quantity, which by its additional weight may place the whole upon a ballance. To illuſtrate this more particularly I ſhall make uſe of fig. 116 In which let ACBD be a circle, by whoſe revolution about the diameter AB a globe ſhould be formed, repreſenting a globe of ſolid earth. Suppoſe this globe covered on all ſides with water to the ſame height, ſuppoſe that of EA or BF, at which diſtance the circle EGFH ſurrounds the circle ACBD; then it is evident, if the globe of earth be at reſt, the water which ſurrounds it will reſt in that ſituation. But if the globe be turned inceſſantly about its axis AB, and the water have likewiſe the ſame motion, it is alſo evident, from what has been explained, that the water between the circles EHFG and ADBC will remain no longer in the preſent ſituation, the parts of it between H and D, and between G and C being by this rotation become lighter, than the parts between E and A and between B and F; ſo that the water over the poles A and B muſt of neceſſity ſubſide, and the

water be accumulated over D and C, till the greater quantity in theſe latter places ſupply the defect of its weight. This would be the caſe, were the globe all covered with water. And the ſame figure of the ſurface would alſo be preſerved; if ſome part of the water ~~adjoining to the globe~~ in any part of it were turned into ſolid earth, as is too evident to need any proof; becauſe the parts of the water remaining at reſt, it is the ſame thing, whether they continue in the ſtate of being eaſily ſeparable, which denominates them fluid, or were to be conſolidated together, ſo as to make a hard body: and this, though the water ſhould in ſome places be thus conſolidated, even to the ſurface of it. Which ſhews that the form of the ſolid part of the earth makes no alteration in the figure the water will take: and by conſequence in order to the preventing ſome parts of the earth from being entirely overflowed, and other parts quite deſerted, the ſolid parts of the earth muſt have given them much the ſame figure, as if the whole earth were covered on all ſides with water.

34. FARTHER, I ſay, this figure of the earth is the ſame, as it would receive, were it entirely a globe of water, provided that water were of the ſame denſity as the ſubſtance of the globe. For ſuppoſe the globe ACBD to be liquified, and that the globe EHFG, now entirely water, by its rotation about its axis ſhould receive ſuch a figure as we have been deſcribing, and then the globe ACBD ſhould be conſolidated again, the figure of the water would plainly not be altered, by ſuch a conſolidation.

35. BUT from this laſt obſervation our author is enabled to determine the proportion between the axis of the earth drawn from pole to pole, and the diameter of the equator, upon the ſuppoſition that all the parts of the earth are of equal denſity; which he does by computing in the firſt place the proportion of the centrifugal force of the parts under the equator to the power of gravity; and then by conſidering the earth as a ſpheroid, made by the revolution of an ellipſis about its leſſer axis, that is, ſuppoſing the line MILK to be an exact ellipſis, from which it can differ but little, by reaſon that the difference between the leſſer axis ML and the greater IK is but very ſmall. From this ſuppoſition, and what was proved before, that all the particles which compoſe the earth have the attracting power explained in the preceding chapter, he finds at what diſtance the parts under the equator ought to be removed from the center, that the force, with which they ſhall be attracted to the center, diminiſhed by their centrifugal force, ſhall be ſufficient to keep thoſe parts in a ballance with thoſe which lie under the poles. And upon the ſuppoſition of all the parts of the earth having the ſame degree of denſity, the earth's ſurface at the equator muſt be above 17 miles more diſtant from the center, than at the poles[a].

36. AFTER this it is ſhewn, from the proportion of the equatorial diameter of the earth to its axis, how the ſame may be determined of any other planet, whoſe denſity in

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[a] Newton Princ. Lib. III prop. 19.

compariſon of the denſity of the earth, and the time of its revolution about its axis, are known. And by the rule delivered for this, it is found, that the diameter of the equator in Jupiter ſhould bear to its axis about the proportion of 10 to 9[a], and accordingly this planet appears of an oval form to the aſtronomers. The moſt conſiderable effects of this ſpheroidical figure our author takes likewiſe into conſideration; one of which is that bodies are not equally heavy in all diſtances from the poles; but near the equator, where the diſtance from the center is greateſt, they are lighter than towards the poles: and nearly in this proportion, that the actual power, by which they are drawn to the center, reſulting from the difference between their abſolute gravity and centrifugal force, is reciprocally as the diſtance from the center. That this may not appear to contradict what has before been ſaid of the alteration of the power of gravity, in proportion to the change of the diſtance from the center, it is proper carefully to remark, that our author has demonſtrated three things relating hereto: the firſt is, that decreaſe of the power of gravity as we recede from the center, which has been fully explained in the laſt chapter, upon ſuppoſition that the earth and planets are perfect ſpheres, from which their difference is by many degrees too little to require notice for the purpoſes there intended: the next is, that whether they be perfect ſpheres, or exactly ſuch ſpheroids as have now been mentioned, the power of gravity, as we deſcend in the ſame line to the center, is at all diſtances as the diſtance from the center, the parts of the earth above the body by drawing the body towards them leſſening its gravitation towards the center[a]; and both theſe aſſertions relate to gravity alone: the third is what we mentioned in this place, that the actual force on different ~~parts of the ſurface~~, with which bodies are drawn to the center, is in the proportion here aſſigned[b].

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[a] Lib. III prop. 19.

38. The next effect of this figure of the earth is an obvious conſequence of the former: that pendulums of the ſame length do not in different diſtances from the pole make their vibrations in the ſame time; but towards the poles, where the gravity is ſtrongeſt, they move quicker than near the equator, where they are leſs impelled to the center; and accordingly pendulums, that meaſure the ſame time by their vibrations, muſt be ſhorter near the poles than at a greater diſtance. Both which deductions are found true in fact; of which our author has recounted particularly ſeveral experiments, in which it was found, that clocks exactly adjuſted to the true meaſure of time at Paris, when tranſported nearer to the equator, became erroneous and moved too ſlow, but were reduced to their true motion by contracting their pendulums. Our author is particular in remarking, how much they loſt of their motion, while the pendulums remained unaltered; and what length the obſervers are ſaid to have ſhortened them, to bring them to time. And the experiments, which appear to be moſt carefully made, ſhew the earth to be raiſed in the middle between the poles, as much as our author found it by his computation[c].

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[a] Lib. I. prop. 73.

[b] Lib. III. prop. 20.

[c] Ibid.

39. THESE experiments on the pendulum our author has been very exact in examining, inquiring particularly how much the extenſion of the rod of the pendulum by the great heats in the torrid zone might make it neceſſary to ſhorten it: For by an experiment ~~made by PICART, and~~ another made by DE LA HIRE, heat, though not very intenſe, was found to increaſe the length of rods of iron. The experiment of PICART was made with a rod one foot long, which in winter, at the time of froſt, was found to increaſe in length by being heated at the fire. In the experiment of DE LA HIRE a rod of ſix foot in length was found, when heated by the ſummer ſun only, to grow to a greater length, than it had in the aforeſaid cold ſeaſon. From which obſervations a doubt has been raiſed, whether the rod of the pendulums in the aforementioned experiments was not extended by the heat of thoſe warm climates to all that exceſs of length, the obſervers found themſelves obliged to leſſen them by. But the experiments now mentioned ſhew the contrary. For in the firſt of them the rod of a foot long was lengthened no more than $\frac{1}{9}$ part of what the pendulum under the equator muſt be diminiſhed; and therefore a rod of the length of the pendulum would not have been extended above $\frac{1}{3}$ of that length. In the experiment of DE LA HIRE, where the heat was leſs, the rod of ſix foot long was extended no more than $\frac{3}{10}$ of what the pendulum muſt be ſhortened; ſo that a rod of the length of the pendulum would not have gained above $\frac{3}{20}$ or $\frac{1}{7}$ of that length. And the heat in this latter experiment, though leſs than in the former, was yet greater than the rod of a pendulum can or-

dinarily contract in the hotteſt country; for metals receive a great heat when expoſed to the open ſun, certainly much greater than that of a human body. But pendulums are not uſually ſo expoſed, and without doubt in theſe experiments were kept cool enough to appear ſo to the touch; which they would do in the hotteſt place, if lodged in the ſhade. Our author therefore thinks it enough to allow about $\frac{1}{10}$ of the difference obſerved upon account of the greater warmth of the pendulum.

40. THERE is a third effect, which the water has on the earth by changing its figure, that is taken notice of by our author; for the explaining of which we ſhall firſt prove, that bodies deſcend perpendicularly to the ſurface of the earth in all places. The manner of collecting this from obſervation, is as follows. The ſurfaces of all fluids reſt parallel to that part of the ſurface of the ſea, which is in the ſame place with them, to the figure of which, as has been particularly ſhewn, the figure of the whole earth is formed. For if any hollow veſſel, open at the bottom, be immerſed into the ſea; it is evident, that the ſurface of the ſea within the veſſel will retain the ſame figure it had, before the veſſel incloſed it; ſince its communication with the external water is not cut off by the veſſel. But all the parts of the water being at reſt, it is as clear, that if the bottom of the veſſel were cloſed, the figure of the water could receive no change thereby, even though the veſſel were raiſed out of the ſea; any more than from the inſenſible alteration of the power of gravity, conſequent upon the augmentation of

the diſtance from the center. But now it is clear, that bodies deſcend in lines perpendicular to the ſurfaces of quieſcent fluids; for if the power of gravity did not act perpendicularly to the ſurface of fluids, bodies which ſwim on them could not reſt, as they are ſeen to do; ~~becauſe, if the power~~ of gravity drew ſuch bodies in a direction oblique to the ſurface whereon they lay, they would certainly be put in motion, and be carried to the ſide of the veſſel, in which the fluid was contained, that way the action of gravity inclined.

41. HENCE it follows, that as we ſtand, our bodies are perpendicular to the ſurface of the earth. Therefore in going from north to ſouth our bodies do not keep in a parallel direction. Now in all diſtances from the pole the ſame length gone on the earth will not make the ſame change in the poſition of our bodies, but the nearer we are to the poles, we muſt go a greater length to cauſe the ſame variation herein. Let MILK (in fig. 117) repreſent the figure of the earth, M, L the poles, I, K two oppoſite points in the middle between theſe poles. Let TV and PO be two arches, TV being moſt remote from the pole L; draw TW, VX, PQ, OR, each perpendicular to the ſurface of the earth, and let TW, VX meet in Y, and PQ, OR in S. Here it is evident, that in paſſing from V to T the poſition of a man's body would be changed by the angle under TYV, for at V he would ſtand in the line YV continued upward, and at T in the line YT; but in paſſing from O to P the poſition of his body would be changed by

the angle under OSP. Now I ſay, if theſe two angles are equal the arch OP is longer than TV: for the figure MILK being oblong, and IK longer than ML, the figure will be more incurvated toward I than toward L; ſo that the lines TW and YX will meet in Y before they are drawn out to ſo great a length as the lines PQ and OR muſt be continued to, before they will meet in S. Since therefore YT and YV are ſhorter than PS and SV, TV muſt be leſs than OP. If theſe angles under TYV and OSP are each $\frac{1}{90}$ part of the angle made by a perpendicular line, they are ſaid each to contain one degree. And the unequal length of theſe arches OP and VT gives occaſion to the aſſertion, that in paſſing from north to ſouth the degrees on the earth's ſurface are not of an equal length, but thoſe near the pole longer than thoſe toward the equator. For the length of the arch on the earth lying between the two perpendiculars, which make an angle of a degree with each other, is called the length of a degree on the earth's ſurface.

42. This figure of the earth has ſome effect on eclipſes. It has been obſerved above, that ſometimes the nodes of the moon's orbit lie in a ſtraight line drawn from the ſun to the earth; in which caſe the moon will croſs the plane of the earth's motion at the new and full. But whenever the moon paſſes near the plane at the full, ſome part of the earth will intercept the ſun's light, and the moon ſhining only with light borrow'd from the ſun, when that light is prevented from falling on any part of the moon, ſo much of her body will be darkened. Alſo when the moon at the

new is near the plane of the earth's motion, the inhabitants on ſome part of the earth will ſee the moon come under the ſun, and the ſun thereby be covered from them either wholly or in part. Now the figure, which we have ſhewn to belong to the earth, will occaſion the ſhadow of the earth on the moon not to be perfectly round, but cauſe the diameter from eaſt to weſt to be ſomewhat longer than the diameter from north to ſouth. In eclipſes of the ſun this figure of the earth will make ſome little difference in the place, where the ſun ſhall appear wholly or in any given part covered. Let ABCD (in fig. 118.) repreſent the earth, AC the axis whereon it turns daily, E the center. Let FAGC repreſent a perfect globe inſcribed within the earth. Let HI be a line drawn through the centers of the ſun and moon, croſſing the ſurface of the earth in K, and the ſurface of the globe inſcribed in L. Draw EL, which will be perpendicular to the ſurface of the globe in L: and draw likewiſe KM, ſo that it ſhall be perpendicular to the ſurface of the earth in K. Now whereas the eclipſe would appear central at L, if the earth were the globe AGCF, and does really appear ſo at K; I ſay, the latitude of the place K on the real earth is different from the latitude of the place L on the globe FAGC. What is called the latitude of any place is determined by the angle which the line perpendicular to the ſurface of the earth at that place makes with the axis; the difference between this angle, and that made by a perpendicular line or ſquare being called the latitude of each place. But it might here be proved, that the angle which KM makes with MC is leſs, than the angle made between LE and EC: conſequently

quently the latitude of the place K is greater, than the latitude, which the place L would have.

43. THE next effect, which follows from this figure of the earth, is that gradual change in the diſtance of the fixed ſtars from the equinoctial points, which aſtronomers obſerve. But before this can be explained, it is neceſſary to ſay ſomething more particular, than has yet been done, concerning the manner of the earth's motion round the ſun.

44. IT has already been ſaid, that the earth turns round each day on its own axis, while its whole body is carried round the ſun once in a year. How theſe two motions are joined together may be conceived in ſome degree by the motion of a bowl on the ground, where the bowl in rouling on continually turns upon its axis, and at the ſame time the whole body thereof is carried ſtraight on. But to be more expreſs let A (in fig. 119) repreſent the ſun BCDE four different ſituations of the earth in its orbit moving about the ſun. In all theſe let FG repreſent the axis, about which the earth daily turns. The points F, G are called the poles of the earth; and this axis is ſuppoſed to keep always parallel to it ſelf in every ſituation of the earth; at leaſt that it would do ſo, were it not for a minute deviation, the cauſe whereof will be explained in what follows. When the earth is in B, the half HIK will be illuminated by the ſun, and the other half HLK will be in darkneſs. Now if on the globe any point be taken

in the middle between the poles, this point ſhall deſcribe by the motion of the globe the circle MN, half of which is in the enlightened part of the globe, and half in the dark part. But the earth is ſuppoſed to move round its axis with an equable motion; therefore ~~on this point~~ of the globe the ſun will be ſeen juſt half the day, and be inviſible the other half. And the ſame will happen to every point of this circle, in all ſituations of the earth during its whole revolution round the ſun. This circle MN is called the equator, of which we have before made mention.

45. Now ſuppoſe any other point taken on the ſurface of the globe toward the pole F, which in the diurnal revolution of the globe ſhall deſcribe the circle OP. Here it appears that more than half this circle is enlightned by the ſun, and conſequently that in any particular point of this circle the ſun will be longer ſeen than lie hid, that is the day will be longer than the night. Again if we conſider the ſame circle OP on the globe ſituated in D the oppoſite part of the orbit from B, we ſhall ſee, that here in any place of this circle the night will be as much longer than the day.

46. In theſe ſituations of the globe of earth a line drawn from the ſun to the center of the earth will be obliquely inclined toward the axis FG. Now ſuppoſe, that ſuch a line drawn from the ſun to the center of the earth, when in C or E, would be perpendicular to the axis FG;

in which caſes the ſun will ſhine perpendicularly upon the equator, and conſequently the line drawn from the center of the earth to the ſun will croſs the equator, as it paſſes through the ſurface of the earth; whereas in all other ſituations of the globe this line will paſs through the ſurface of the globe at a diſtance from the equator either northward or ſouthward. Now in both theſe caſes half the circle O P will be in the light, and half in the dark; and therefore to every place in this circle the day will be equal to the night. Thus it appears, that in theſe two oppoſite ſituations of the earth the day is equal to the night in all parts of the globe; but in all other ſituations this equality will only be found in places ſituated in the very middle between the poles, that is, on the equator.

47. THE times, wherein this univerſal equality between the day and night happens, are called the equinoxes. Now it has been long obſerved by aſtronomers, that after the earth hath ſet out from either equinox, ſuppoſe from E (which will be the ſpring equinox, if F be the north pole) the ſame equinox ſhall again return a little before the earth has made a compleat revolution round the ſun. This return of the equinox preceding the intire revolution of the earth is called the preceſſion of the equinox, and is cauſed by the protuberant figure of the earth.

48. SINCE the ſun ſhines perpendicularly upon the equator, when the line drawn from the ſun to the center of the earth is perpendicular to the earth's axis, in this caſe

the plane, which ſhould cut through the earth at the equator, may be extended to paſs through the ſun; but it will not do ſo in any other poſition of the earth. Now let us conſider the prominent part of the earth about the equator, as a ſolid ring moving with the earth round the ſun. At the time of the equinoxes, this ring will have the ſame kind of ſituation in reſpect of the ſun, as the orbit of the moon has, when the line of the nodes is directed to the ſun; and at all other times will reſemble the moon's orbit in other ſituations. Conſequently this ring, which otherwiſe would keep throughout its motion parallel to it ſelf, will receive ſome change in its poſition from the action of the ſun upon it, except only at the time of the equinox. The manner of this change may be underſtood as follows. Let A B C D (in fig. 120) repreſent this ring, E the center of the earth, S the ſun, A F C G a circle deſcribed in the plane of the earth's motion to the center E. Here A and C are the two points, in which the earth's equator croſſes the plane of the earth's motion; and the time of the equinox falls out, when the ſtraight line A C continued would paſs through the ſun. Now let us recollect what was ſaid above concerning the moon, when her orbit was in the ſame ſituation with this ring. From thence it will be underſtood, if a body were ſuppoſed to be moving in any part of this circle A B C D, what effect the action of the ſun on the body would have toward changing the poſition of the line A C. In particular H I being drawn perpendicular to S E, if the body be in any part of this circle between A and H, or between C and I, the line A C